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# Status of the Transverse Single Spin Asymmetry of p+p↑ → η+X at √s = 200 GeV

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## For the PHENIX Collaboration

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# Transverse Single Spin Asymmetry ($A_N$)

**Definition of $A_N$**: The ratio of the difference and the sum of the transverse **spin-dependent** differential cross-sections of a **certain interaction**, eg. inclusive hadron production (η mesons)
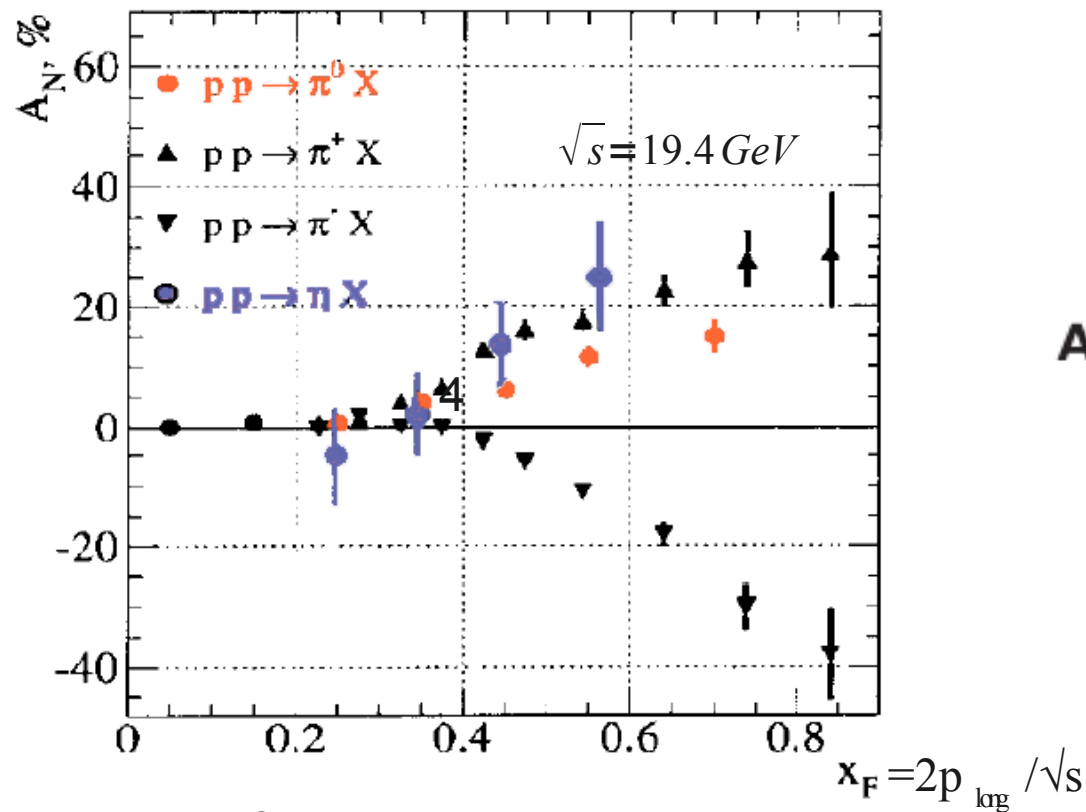
$$A_N = \frac{d\sigma_\uparrow(\phi) - d\sigma_\downarrow(\phi)}{d\sigma_\uparrow(\phi) + d\sigma_\downarrow(\phi)}$$



$: d\sigma_\uparrow$

$: d\sigma_\downarrow$
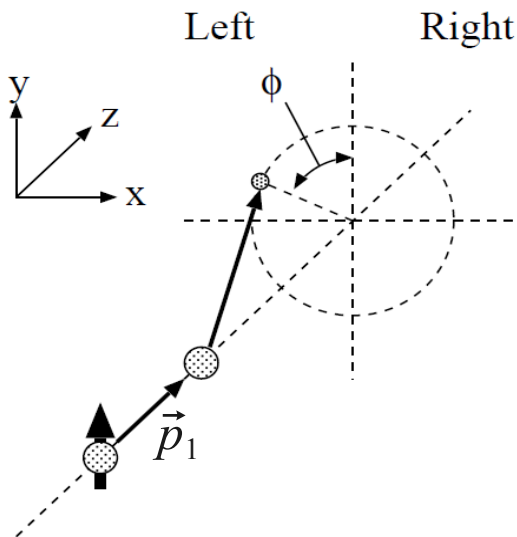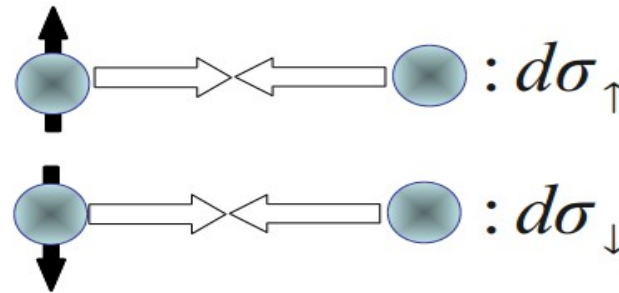


- $A_N$ is an azimuthal, or "left-right" asymmetry

- See if there is a **difference** in the production of η mesons to the **left-right** in pp$^\uparrow$ interactions.
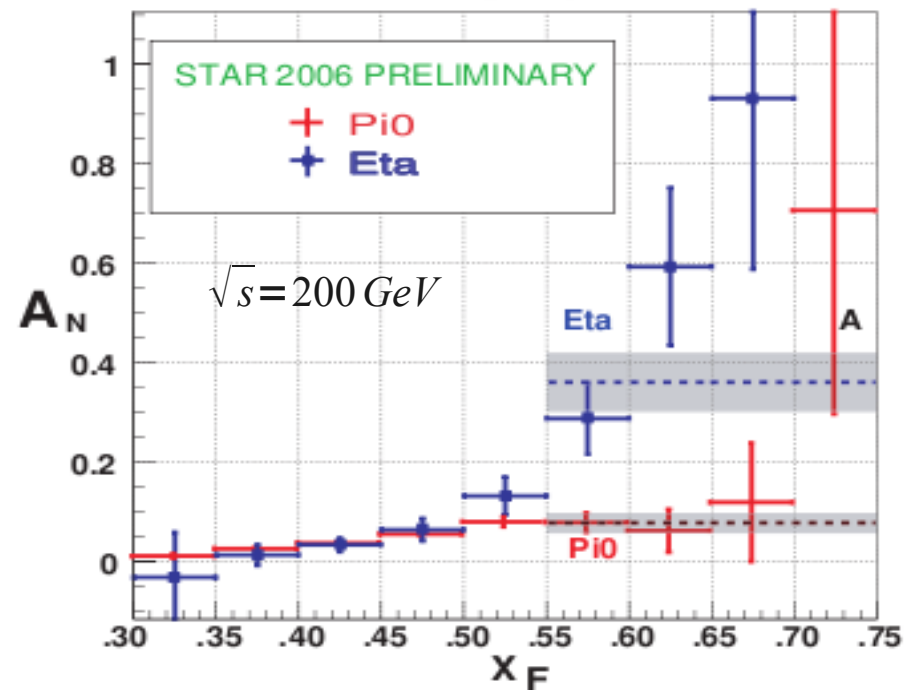
- *Has $A_N$ been measured before?*

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# A$_N$ by other experiments

- A$_N$ of order $10^{-1}$ observed in polarized hadronic collisions over wide range of energies since 1970s.

- STAR sees nonzero A$_N$ for ηs (2006 Run at RHIC)

- <span style="color:red">PHENIX will attempt to measure η A$_N$ at √s = 200GeV</span>

# Origin of A$_N$

**Proton Structure**

**pQCD**

$$\frac{d^3\sigma^\uparrow\left(pp^\uparrow \to hX\right)}{dx_1 dx_2 dz} \propto \hat{q}(x_1, k_{q,T}) \cdot G(x_2) \times \frac{d^3\hat{\sigma}^\uparrow(q_i q_j \to q_k q_l)}{dx_1 dx_2} \times FF_{q_{k,l}}(z, p_{h,T})$$

small spin
dependence

**fragmentation
function**
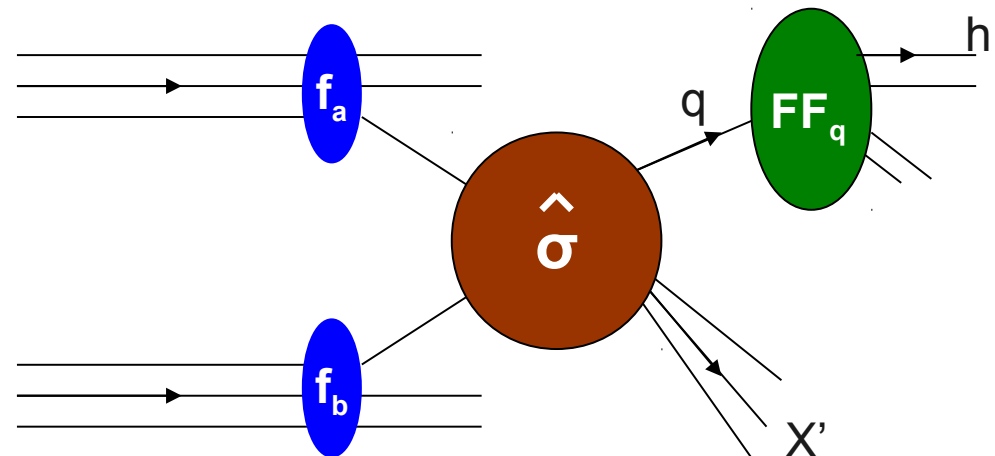
# Origin of A$_N$

$$\frac{d^3\sigma^\uparrow\left(pp^\uparrow\to hX\right)}{dx_1 dx_2 dz} \propto q_i^\uparrow(x_1,k_{q,T})\cdot G(x_2) \times \frac{d^3\hat{\sigma}^\uparrow(q_i q_j \to q_k q_l)}{dx_1 dx_2} \times FF_{q_{k,l}}(z,p_{h,T})$$

**Proton Structure**
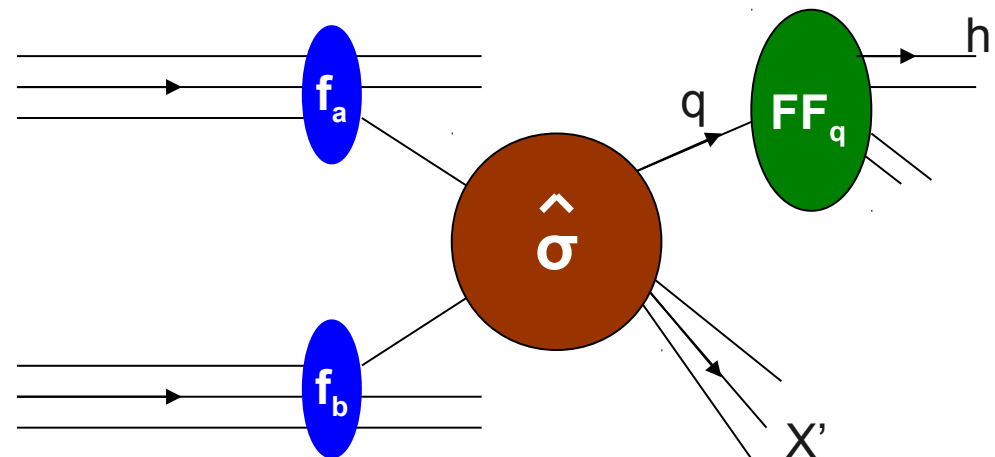
**pQCD**

small spin dependence

**fragmentation function**

## A$_N$ Observables:

- **"Transversity" quark-distributions and Collins fragmentation**

  - Correlation between proton and quark-spin and spin dependent fragmentation

  $$A_N \propto \delta q(x) \cdot H_1^{(\perp,<)}(z_2,k^2)$$

- **Sivers quark distribution**

  - Correlation between proton spin and transverse quark momentum

  $$A_N \propto f_{1T}^{\perp q}(x,k_\perp^2) \cdot D_q^h(z)$$

(diagram with f$_a$, f$_b$, $\hat{\sigma}$, FF$_q$, q, h, X')

- **MPC is forward E.M. Calorimeter**
  - Pseudorapidity ~ 3.1-3.9 North, -3.1-(-3.7) South
  - 220 cm from nominal interaction point
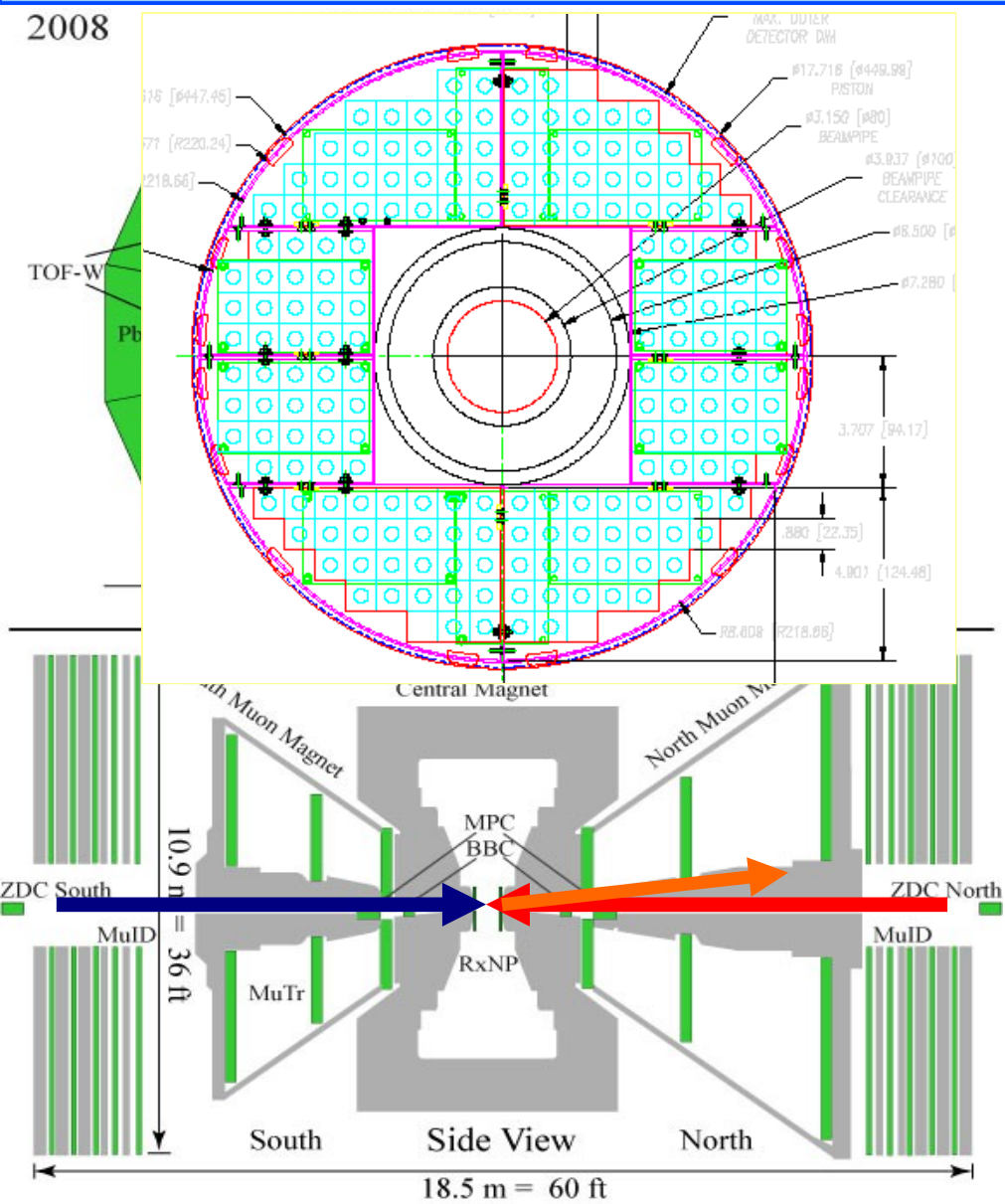  - 2.2x2.2x18 cm$^3$ PbWO$_4$ crystal towers

# MPC detector in PHENIX

- **MPC is forward E.M. Calorimeter**
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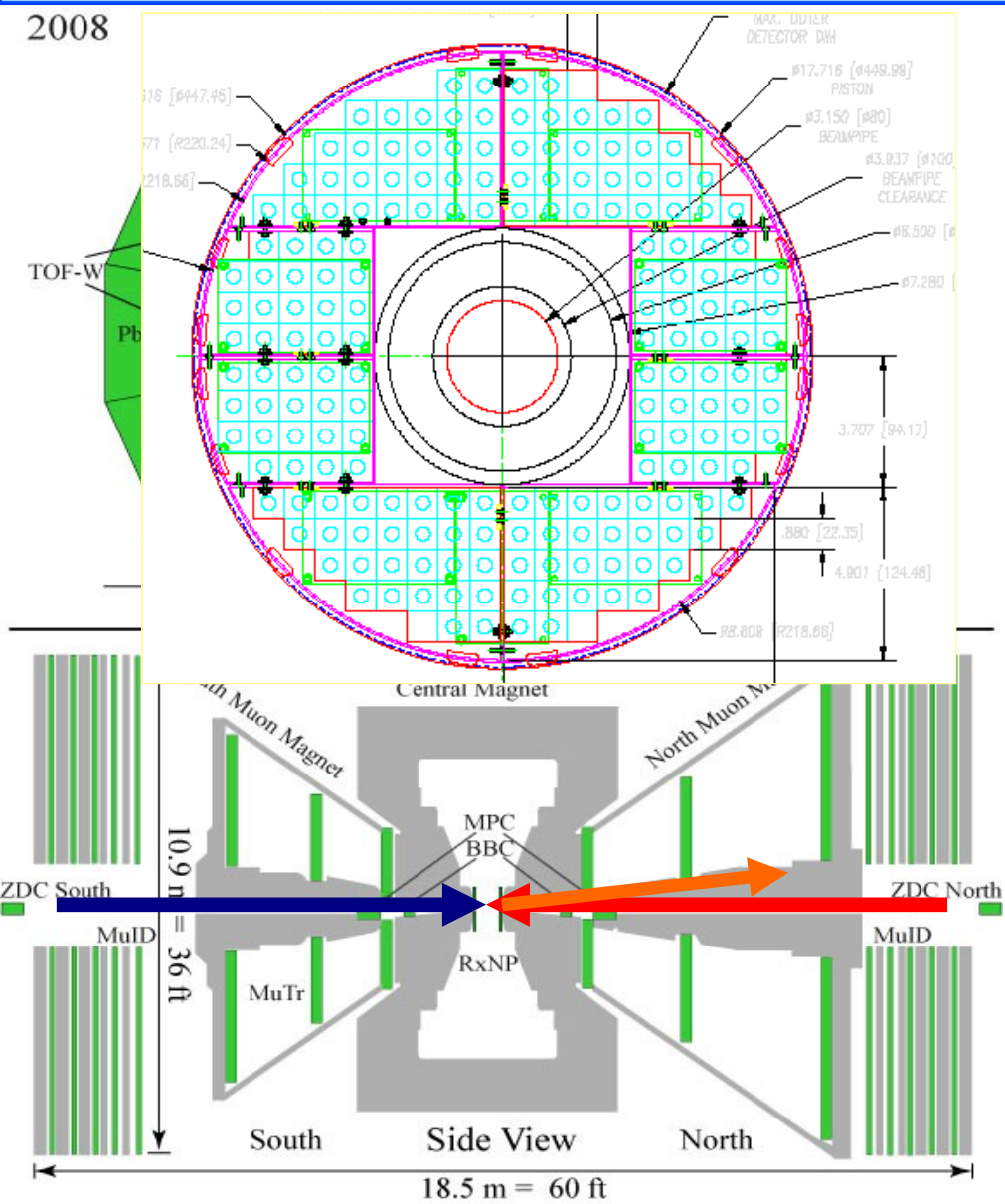    - 2.2x2.2x18 $cm^3$ $PbWO_4$ crystal towers

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- 2008 Run (p+p$^\uparrow$ at $\sqrt{s}$ = 200GeV) at RHIC
  - 5.2 $pb^{-1}$ integated luminosity
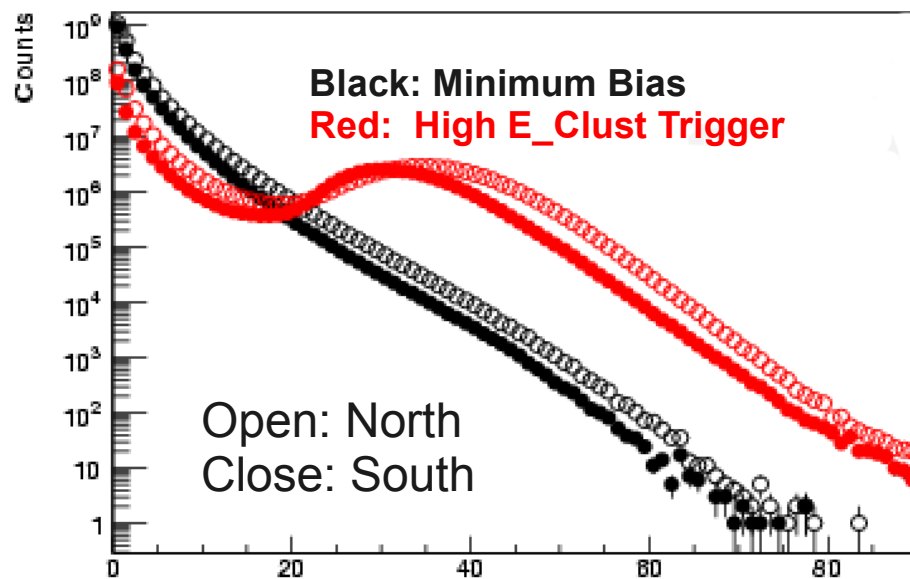  - 45% vertical beam polarization

# Extracting the η Meson Counts

$M_\eta$ = 547 MeV/c$^2$

Primary Decay Modes:

$\eta \rightarrow \gamma + \gamma$      (39.3%)

$\eta \rightarrow \pi^0 + \pi^0 + \pi^0$  (32.5%)

$\eta \rightarrow \pi^+ + \pi^- + \pi^0$ (22.7%)
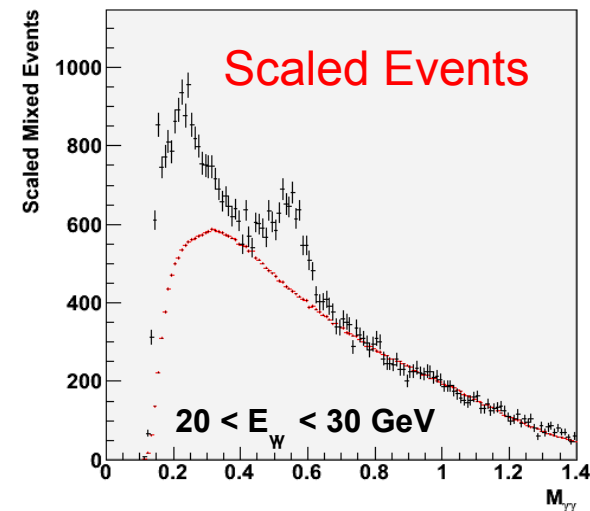


Black: Minimum Bias
Red: High E_Clust Trigger

Open: North
Close: South

- Calculate invariant mass for cluster pairs
  - Use high energy cuts on clusters, cluster pairs
    - E_Cluster > 4.0 GeV
    - E_Pair > 20.0 GeV
- Two Data sets used
  - Minimum bias trigger
  - High energy cluster trigger
    - 4x4 tower sum > 20.0 GeV fires the trigger

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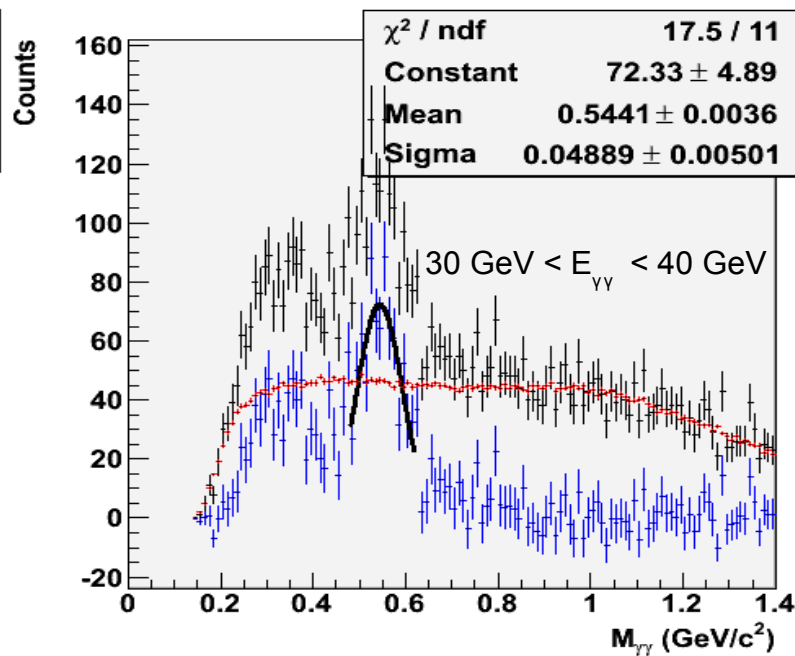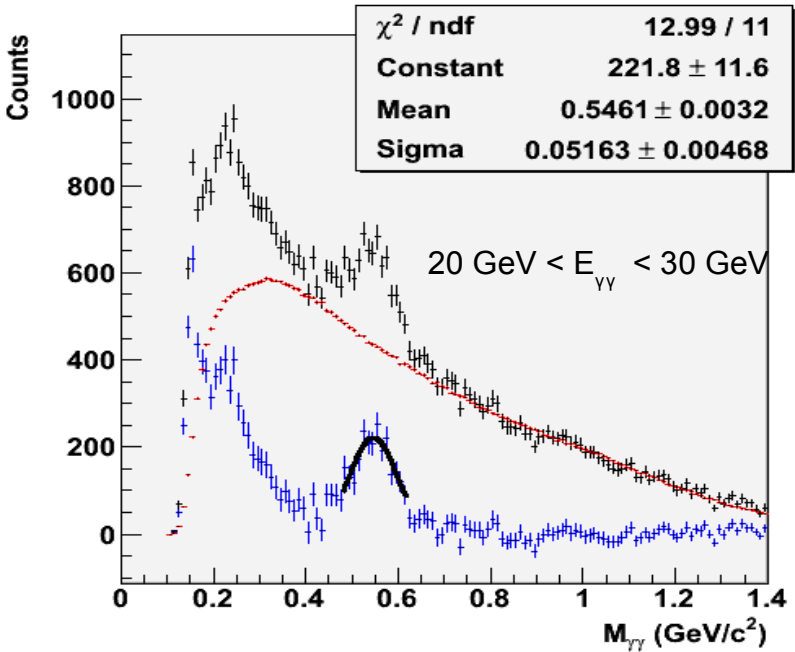
# Extracting the η Meson Counts

(Exemplary for one energy bin)
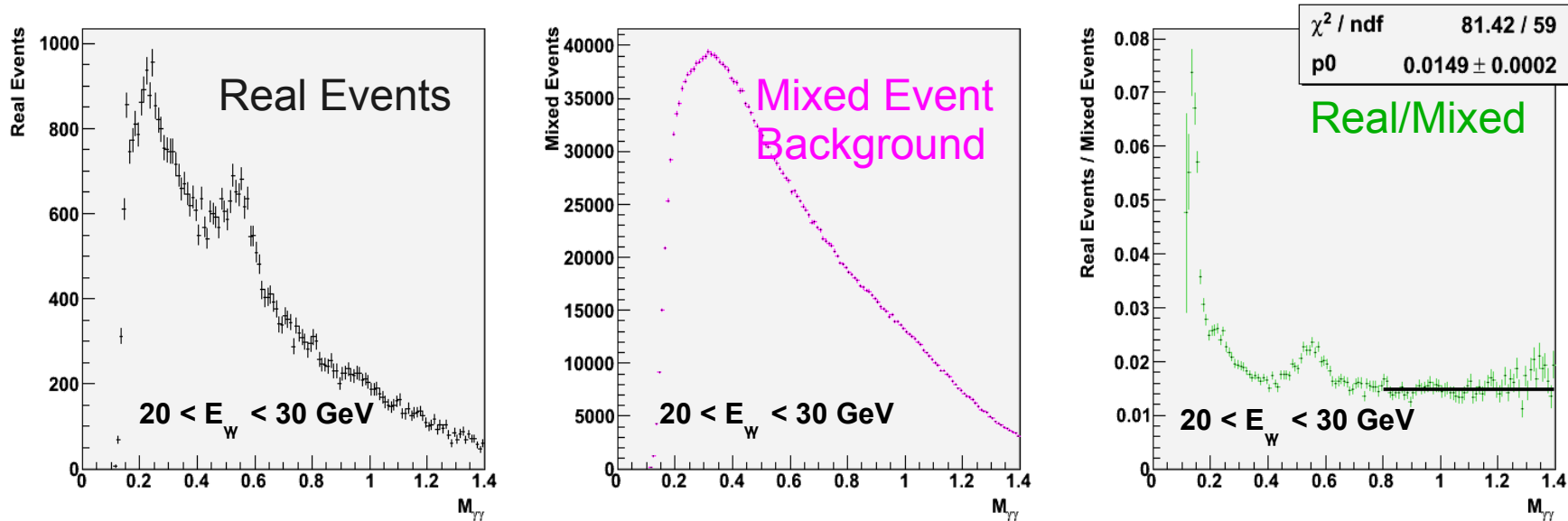


- *How do we normalize out the background?*

- Take **Real Events**/**Mixed Events** **(S/B)**, and fit with constant, **C**

- **Scaled Mixed Events** = **C*Mixed**

- **Raw Counts** = **Real** - **Scaled**

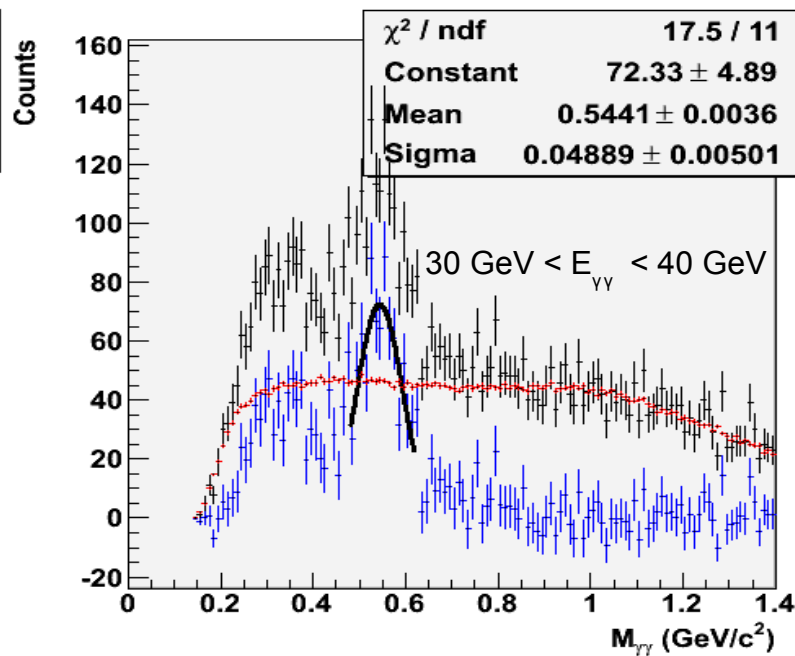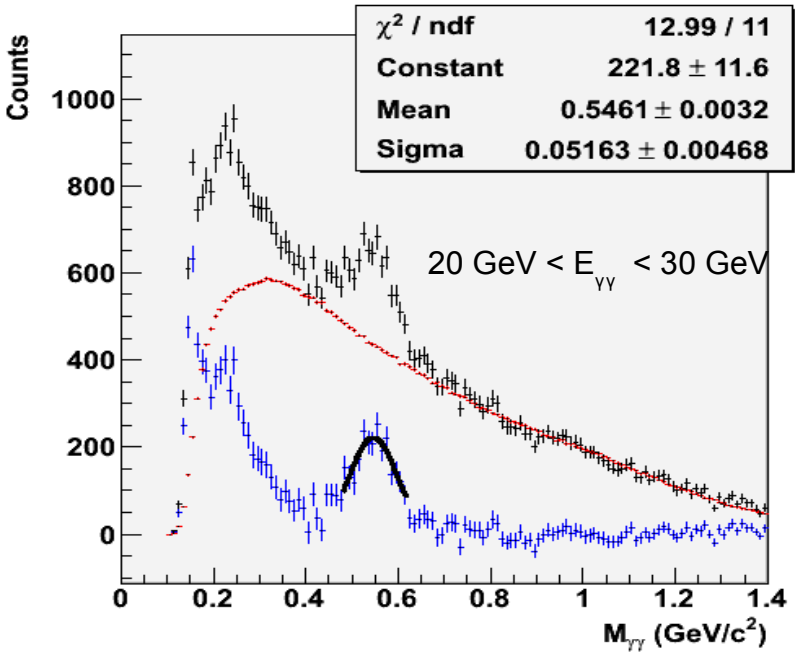# η Counts Minimum Bias



**Real Events**
**Scaled Mixed Events**
**Raw Counts**

- ## Clear Signal

- ## Correlated Background at 0.2-0.4 GeV

  - High energy $\pi^0$ Clusters (E > 20 GeV) merge, possibly producing jet correlations

  - Under investigation

# η Counts Minimum Bias



$20\ \text{GeV} < E_{\gamma\gamma} < 30\ \text{GeV}$

| $\chi^2$ / ndf | 12.99 / 11 |
| --- | --- |
| Constant | $221.8 \pm 11.6$ |
| Mean | $0.5461 \pm 0.0032$ |
| Sigma | $0.05163 \pm 0.00468$ |

$30\ \text{GeV} < E_{\gamma\gamma} < 40\ \text{GeV}$

| $\chi^2$ / ndf | 17.5 / 11 |
| --- | --- |
| Constant | $72.33 \pm 4.89$ |
| Mean | $0.5441 \pm 0.0036$ |
| Sigma | $0.04889 \pm 0.00501$ |

**Real Events**
**Scaled Mixed Events**
**Raw Counts**

- ## Clear Signal

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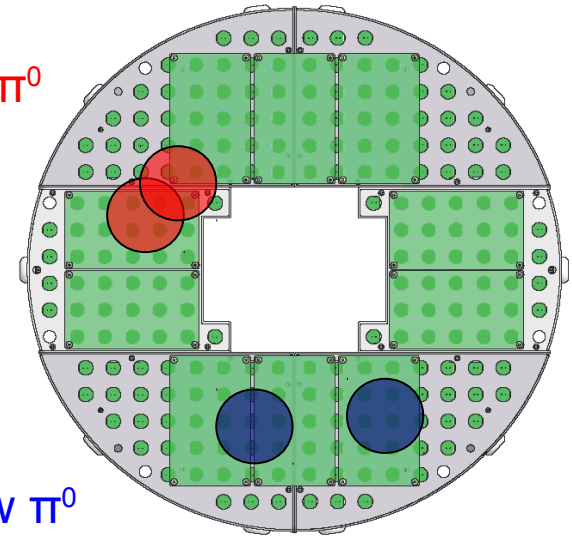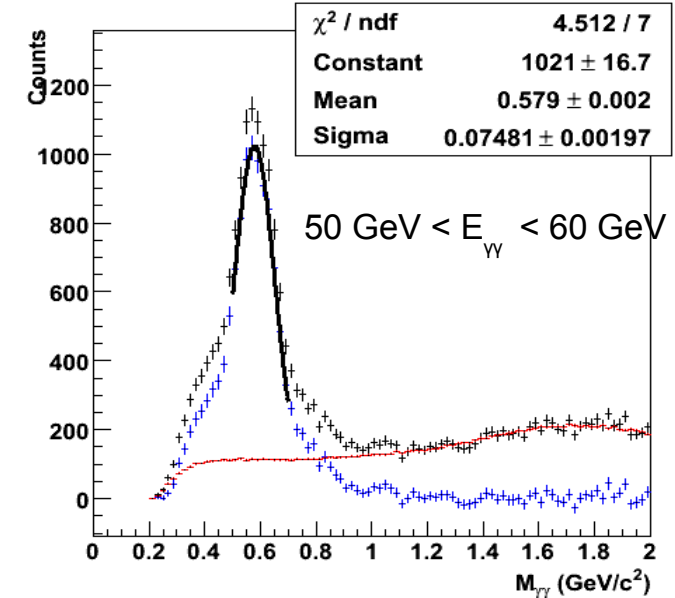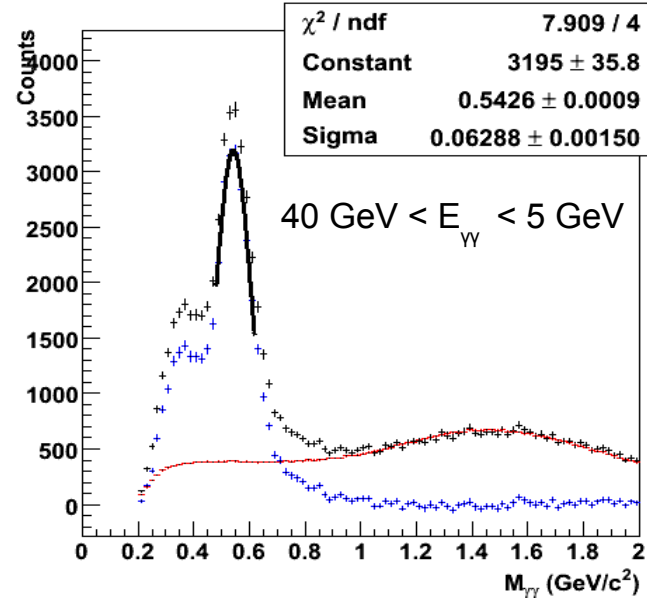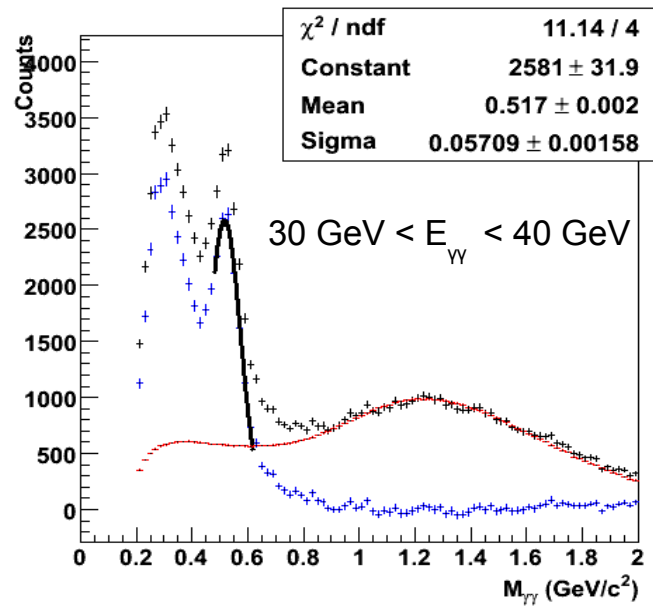
High $\pi^0$

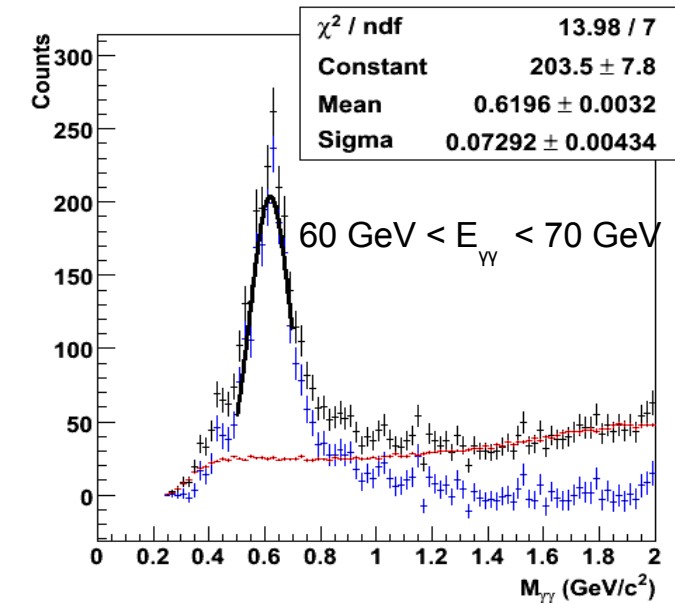Low $\pi^0$

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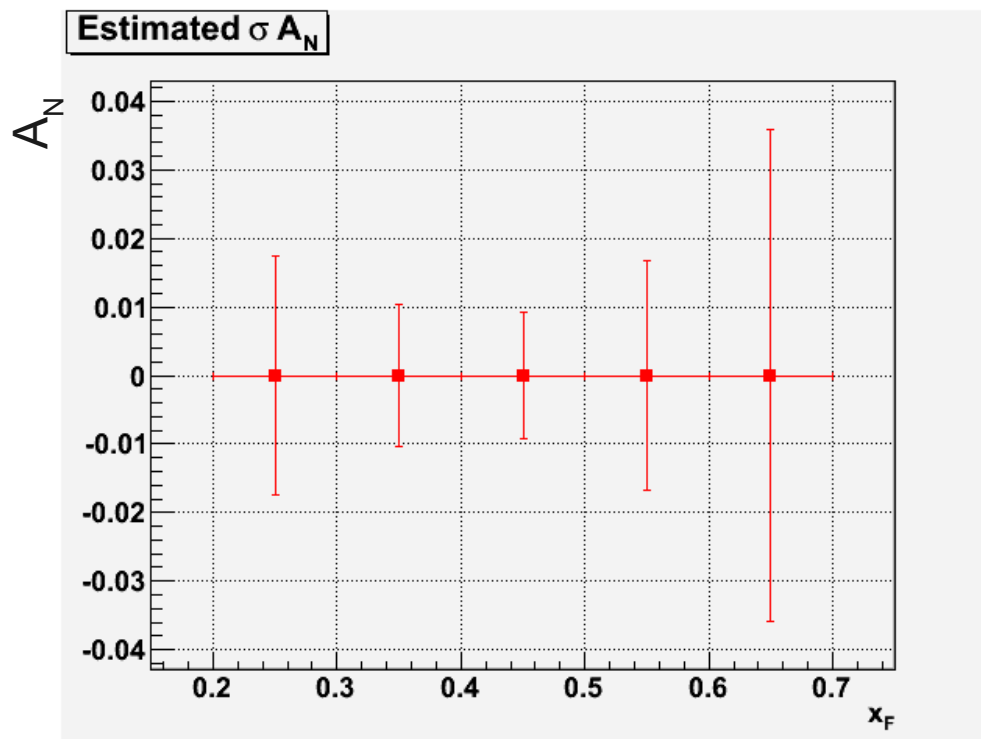
# η Counts High Energy Cluster Trigger



- Clear Signal, improved S/B at higher energies
- Again, Correlated Background at 0.2-0.4 GeV
  - Shifts to the right as energy increases
- Investigate with Simulations

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# Estimated uncertainty in σA$_N$

$$\sigma A_N \sim \frac{\Box}{pol} \times \frac{\blacksquare}{\sqrt{\Box N}}$$

Estimated Error for zero asymmetry (=maximum error)



**Estimated σ A$_N$**

(plot: A$_N$ vs x$_F$, with data points at zero and error bars)

$$x_F = 2p_{long} / \sqrt{s}$$

- Beam Polarization P = 46%

- Factor of 2 comes from the use of both beams polarized

- Does not take into account background subtraction correction

# Summary and Outlook

- Demonstrated capability of measuring $\eta$ mesons in the PHENIX MPC for $0.2 < x_F < 0.7$ in $\sqrt{s} = 200$ GeV $p+p^{\uparrow}$ collisions

- North and South Arms will provide consistency checks

- Tasks

  - Try to understand correlated background

  - Want to subtract the background asymmetry

  - Will look at how $A_N$ behaves in $x_F$, $p_T$, and pseudorapidity.

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